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Combustion of Natural Gas without the Presence of Nitrogen

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Abstract: The following article deals with the consequences of burning natural gas without the presence of atmospheric nitrogen. It is primarily a change in the volumetric flow of flue gas in the exhaust system of the furnace. With the help of modified stoichiometric tables and the flow equation in the chimney, the difference in draft ratios of the furnace draft, when switching from conventional burners to oxygen burners, is demonstrated here on a specific industrial unit.

Keywords: Natural gas; chemical composition; stoichiometric equations; burners; flue gas; chimney.

1. Introduction

Efficient combustion of natural gas (NG) without the presence of nitrogen (N_2) is a challenge for all economically and ecologically minded combustion plant operators. Fuel savings will be manifested in particular by a significant reduction of nitrogen in the combustion air, which will reduce heat loss in the flue gas, as air nitrogen in the combustion process only takes the chemical heat of the fuel and does not participate in the combustion process itself. The net economic profit can then be calculated from the energy balance of combustion, based on 1 m^3 of natural gas.

Attempts at such innovations, however, entail several practical pitfalls, which this article will introduce you to. In particular, this is a significant volume change in the amount of flue gas, for which the original exhaust system is not usually dimensioned. This significantly affects the draft of the chimney. There are known cases when, after the introduction of a similar measure (replacing the original burners with oxygen ones), it was necessary to proceed with the forced extraction of flue gas with a fan (the original chimney stopped pulling), or even to reheat the flue gas by adding a burner to the chimney in order to get the flue gas to its mouth. The main goal of this study is the calculation of the physical consequences of the change in the volume of flue gas on a selected industrial unit.

Combustion without atmospheric oxygen has a number of advantages, mainly for energy and the environment, yet this method of combustion is not very widespread. Based on the author's research, this is mainly due to the operators' concerns not only about interfering with the draft ratios of the furnace, but mainly because of the uncertain future regarding the price of oxygen.

2. Operational Requirements

Pure oxygen is mostly used in combustion processes where, for technological reasons, a very high flame temperature, a high reaction rate, or an increase in performance are required. Oxygen can also be used advantageously for combustion processes in which it is not possible to use the waste heat of the flue gas efficiently. Due to the need to economize energy-intensive combustion processes, the area of oxygen use has continued to expand in recent years. In addition to welding and flame cutting,

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today oxygen is also widely used in metallurgical and chemical operations, in the cement, ceramic and glass industries.

Thanks to the saving of fuel by adding oxygen instead of combustion air, it is possible under certain circumstances to increase the output of furnace aggregates without increasing the overall cost, even in spite of the cost of supplying oxygen. However, when compared to conventional processes, the addition of oxygen, in addition to increasing performance, can also bring lower investment costs, lower costs related to flue gas cleaning, greater process flexibility and better quality of processed material. The composition of the combustion gases of all fossil fuels is calculated using stoichiometric equations, which primarily determine the minimum amount of oxygen (O_{min}), the resulting minimum amount of air (L_{min}) and the amount of gases that do not actively participate in the combustion process itself.

3. Theory of Combustion of Natural Gas without Nitrogen

In conventional combustion processes, air is used as an oxidizing agent. Due to the high proportion of inert nitrogen in the air (approx. 79 %), which only removes heat from the combustion space, only a low level of thermal efficiency and flame temperature can be achieved when burning with air. Industrial furnaces that use pure oxygen (or oxygen-enriched air) as an oxidizer use liquid oxygen to increase the concentration of oxygen in the combustion air, or adsorption devices to remove nitrogen from the air, thereby increasing the proportion of oxygen in it. Some systems feed pure oxygen directly to the burner, while others add oxygen to the combustion

Table 1: Combustion table NG

	Component	Quantity ($m^3 \cdot m^{-3}$)	Omin	Flue gas ($m^3 \cdot m^{-3}$)			
				CO_2	H_2O	N_2	O_2
Methane	CH_4	0.9839	1.968	0.984	1.968		
Nitrogen	N_2	0.0084				0.008	
Ethane	C_2H_6	0.0044	0.015	0.009	0.013		
Propane	C_3H_8	0.0016	0.008	0.005	0.006		
Butane	C_4H_{10}	0.0007	0.005	0.003	0.004		
Carbon dioxide	CO_2	0.0007		0.001			
Nitrogen airy	$N_{2,air}$					8.254	
Oxygen airy	$O_{2,air}$						0.200
	Subtotal	**1.000**	**1.996**	**1.001**	**1.991**	**8.263**	**0.200**
	Total						**11.454**

Table 2: NG combustion table without air N_2

	Component	Quantity ($m^3 \cdot m^{-3}$)	Omin	Flue gas ($m^3 \cdot m^{-3}$)			
				CO_2	H_2O	N_2	O_2
Methane	CH_4	0.9839	1.968	0.984	1.968		
Nitrogen	N_2	0.0084				0.008	
Ethane	C_2H_6	0.0044	0.015	0.009	0.013		
Propane	C_3H_8	0.0016	0.008	0.005	0.006		
Butane	C_4H_{10}	0.0007	0.005	0.003	0.004		
Carbon dioxide	CO_2	0.0007		0.001			
Nitrogen airy	$N_{2,air}$					0.000	
Oxygen airy	$O_{2,air}$						0.200
	Subtotal	**1.000**	**1.996**	**1.001**	**1.991**	**0.008**	**0.200**
	Total						**3.210**

air supply line. Some heating systems use auxiliary oxygen burners in conjunction with standard air burners. Other systems apply a gradual change in oxygen content for different stages of heating.

3.1. Change in the amount of hot flue gas

The stoichiometric equations, subsequently compiled into a combustion table, will allow us to calculate the amount of individual components of the flue gas, based on the declared chemical composition of the fuel, assuming perfect combustion of the fuel (without the formation of CO), with a predefined excess of air [1].

Combustion of 1 m^3 of natural gas using normal combustion air produces 11.45 m^3 of flue gas. The following table 2 shows the stoichiometric calculation of the identical NG, without atmospheric nitrogen.

Burning 1 m^3 of natural gas without atmospheric nitrogen produces 3.21 m^3 of flue gas. The difference in the amount of flue gas amounts to 72%.

3.2. Changing the draft of the chimney

A change in the amount of hot flue gases will change the draft ratios in the flue gas channel and consequently the draft of the chimney. The draft of the chimney is calculated from the modified Bernoulli equation and is a negative pressure that must be greater than the sum of the pressure losses of the flue gas tract. By calculating the geometric and dynamic pressures, minus pressure losses due to friction and local pressure losses, we obtain the theoretical vacuum required to achieve vertical flow in the chimney:

$$\Delta p = h.g\left(\rho_{0,vz}.\frac{T_0}{\overline{T}_{vz}} - \rho_{0,sp}.\frac{T_0}{\overline{T}_{sp}}\right) + \frac{v_{0,1}^2}{2}.\rho_{0,sp}.\frac{T_{1,sp}}{T_0} - \frac{v_{0,2}^2}{2}.\rho_{0,sp}.\frac{T_{2,sp}}{T_0} - \Lambda.\frac{h}{d}.\frac{\overline{v}_0^2}{2}.\rho_{0,sp}.\frac{\overline{T}_{sp}}{T_0} - \xi\frac{v_{0,2}^2}{2}.\rho_{0,sp}.\frac{T_{2,sp}}{T_0} \quad (\mathrm{Pa}) \quad (1)$$

Where: p - pressure (Pa); h - chimney height (m); g - gravitational acceleration (m·s^{-2}); ρ - density (kg·m^{-3}); T - temperature (K); v - velocity (m·s^{-1}); Λ - coefficient of friction (1); d - diameter (m); ξ - local loss coefficient (1),

where the subscripts $_{vz}$ stand for air, $_{sp}$ for flue gas, and the bar above any unit represents its mean value. The auxiliary indices $_1$ and $_2$, which are located in front of them, mean the position at the foot and at the mouth of the chimney, respectively. A zero before the subscripts means substituting the value under normal conditions [1].

4. Calculation Part

On the basis of the previous theoretical relationships, the actual change in the draft of the chimney can be calculated for the observed stationary industrial furnace for heating logs. First, it was necessary to measure the flue gas paths from a specific heat aggregate and the temperature of the flue gas along the entire route, so that we could define the boundary conditions at the bottom of the chimney. Subsequently, it was possible to recalculate the changed pressure losses. The basic parameters for calculating the change in traction for the monitored aggregate were:

Chimney height:	*20 meters*
Chimney diameter (without cone):	*0.3 meters*
Flue gas temperature at the bottom of the chimney:	*300 °C*
Average density of flue gas:	*1.21 kg.m^{-3}*
Reference ambient air temperature:	*20 °C*

Table 3: Measured values of NG consumption and their conversion to the amount of flue gas

Date	*Gas consumption*	*Flue gases*	*Flue gases without N2*
mm.dd.yy	m^3.hr^{-1}	m^3.hr^{-1}	m^3.hr^{-1}
01.02.24	73	802	219
01.03.24	90	989	270
01.04.24	92	1 008	275
01.05.24	122	1 343	366
01.06.24	143	1 569	428
01.07.24	143	1 570	428
01.08.24	78	858	234
01.09.24	99	1 093	298
01.10.24	100	1 096	299
01.11.24	113	1 248	340
01.12.24	55	605	165
01.13.24	113	1 238	338
01.14.24	111	1 222	333
01.15.24	118	1 299	354
01.16.24	99	1 084	296
01.17.24	106	1 165	318
01.18.24	72	788	215
01.19.24	155	1 700	464
01.20.24	50	548	150

The temperatures after the height of the chimney were calculated according to the cooling coefficient of the chimney and thus the average density of the flue gases was optimized. The ambient air temperature was assumed to be summer (20 °C) due to the lower draft of the chimney in the summer months.

The measurement of the actual NG consumption took place in the period from 02.01.2024 to 20.01.2024 and was in the range of 50 – 155 $m^3 \cdot hr^{-1}$, depending on the production program, see the following table 3.

In table 3, the last two columns show the recalculated values of the amount of flue gas generated from previous tables 1 and 2. The coefficient declared by the manufacturer of the burners installed on the monitored industrial furnace was used as excess air.

The following figure 1 graphically shows the difference between the amount of flue gas produced during combustion under normal conditions and without atmospheric nitrogen.

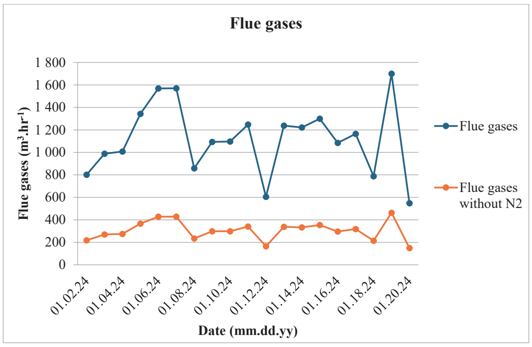


Fig. 1: Graph of changes in the amount of flue gas NG

Based on the amount of flue gas, the change in draft of the chimney was calculated from equation 1, i.e. the negative pressure that the existing chimney can generate for changes in the amount of volume flow, while maintaining the current temperatures.

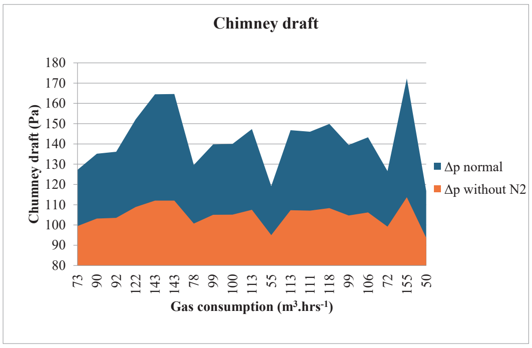
In Table 3, the last two columns show the recalculated values of the chimney draft difference at the current hourly consumption of natural gas under normal conditions and without the presence of nitrogen.

Figure 2 graphically shows the difference in chimney draft during normal combustion and during combustion without air nitrogen.

Table 4: Change in chimney draft (Δp) according to NG consumption

Date	*Gas consumption*	*Δp normal*	*Δp without N2*
mm.dd.yy	$m^3.hr^{-1}$	Pa	Pa
01.02.24	73	127	100
01.03.24	90	135	103
01.04.24	92	136	104
01.05.24	122	152	109
01.06.24	143	165	112
01.07.24	143	165	112
01.08.24	78	130	101
01.09.24	99	140	105
01.10.24	100	140	105
01.11.24	113	147	108
01.12.24	55	119	95
01.13.24	113	147	107
01.14.24	111	146	107
01.15.24	118	150	108
01.16.24	99	140	105
01.17.24	106	143	106
01.18.24	72	127	99
01.19.24	155	172	114
01.20.24	50	117	94

Fig. 2: Graph of changes in chimney thrust



4.1. Change in flue gas flow rate

However, the reduction in the volumetric flow of flue gas will mainly be reflected in the change in the flue gas flow rate. For the needs of operators, the change in average flue gas velocity is the most important information, as there are empirical manuals for ensuring safe flow in flue gas ducts, related to flow velocity.

Table 5 Change in flue gas velocity (w) according to NG consumption

Date	*Gas consumption*	*v normal*	*v without N2*
mm.dd.yy	$m^3.hr^{-1}$	$m.s^{-1}$	$m.s^{-1}$
01.02.24	73	1.48	0.41
01.03.24	90	1.82	0.51
01.04.24	92	1.86	0.52
01.05.24	122	2.47	0.69
01.06.24	143	2.90	0.81
01.07.24	143	2.90	0.81
01.08.24	78	1.58	0.44
01.09.24	99	2.00	0.56
01.10.24	100	2.00	0.56
01.11.24	113	2.29	0.64
01.12.24	55	1.11	0.31
01.13.24	113	2.29	0.64
01.14.24	111	2.25	0.63
01.15.24	118	2.39	0.67
01.16.24	99	2.00	0.56
01.17.24	106	2.15	0.60
01.18.24	72	1.46	0.40
01.19.24	155	3.14	0.88
01.20.24	50	1.01	0.28

In columns three and four, it is possible to see the difference in the flue gas flow rate with the current hourly consumption of natural gas. It can be stated that during normal combustion, the flue gas velocity is in the range of 1 – 3 $m.s^{-1}$, when burning the same amount of NG, the flue gas velocity may drop below 0.3 $m.s^{-1}$, which is below the lowest recommended velocity of 0.5 $m.s^{-1}$, which is given in the professional literature [1].

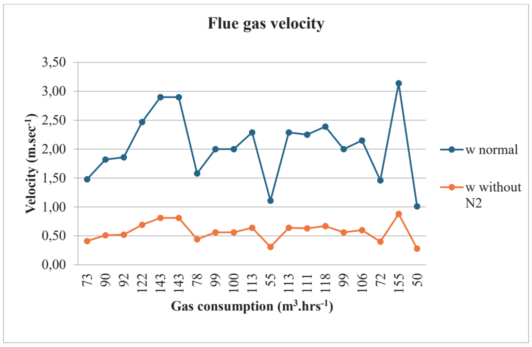


Fig. 3: Graph of flue gas velocity change

Figure 3 graphically shows the difference in the flue gas flow rate during normal combustion and during combustion without air nitrogen.

5. Conclusion

The use of oxygen burners for heating industrial furnaces is a technical solution, the use of which should always be considered due to its technological, economic and ecological possibilities. The use of oxygen burners (or the enrichment of the combustion air with oxygen) is today mentioned among the best available technologies in a number of technological processes. There is a sufficiently wide range of different types of oxygen burners on the market, suitable for a whole range of industrial furnaces. However, in the case of a possible transition to oxygen burners, it will be necessary to recalculate the change in chimney draft according to the above methodology.

The existing monitored chimney was dimensioned for an average flue gas volume flow of approx. 1,000 $m^3·hr^{-1}$, while the velocity of the flue gas was in the range of 1 - 3 $m.s^{-1}$. However, in the case of combustion without atmospheric nitrogen, the velocity of flue gases will drop to 0.3 – 0.8 $m·s^{-1}$ at the lowest NG consumption. However, the flue gas velocity should not be lower than 0.5 $m·s^{-1}$, because then the chimney does not draw properly and it is necessary in some cases to help it with a forced draft.

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